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III. *On Ground Gru, or Ice formed, under peculiar circumstances, at the bottom of Running Water.* By JAMES FARQUHARSON, LL.D. F.R.S., Minister of the Parish of Alford.

Received March 11,—Read March 25, 1841.

IN a paper of mine on Ground Gru, or ice formed at the bottom of running water, which was honoured with a place in the Philosophical Transactions*, I had inferred, from a great many conditions attending a remarkable occurrence of the phenomenon in the rivers Don and Leochal, in the beginning of January 1835, as well as from its occurring only when the air is at the time quite clear, that it is caused, when the water has gone down in temperature to the freezing point, by the bottom of the water being cooled to a still lower temperature, in the same manner as the surface of the dry land, under a clear sky, is cooled down below the temperature of the air, as first demonstrated by the experiments of Dr. WELLS.

As the accuracy of the conclusion at which I arrived respecting the question has been controverted, I respectfully request the Royal Society to permit me to present to them brief notices of some recent occurrences of ground gru, in the same rivers to which I formerly referred, the conditions of which seem to me strongly to confirm the accuracy of the views I presented regarding the cause of the phenomenon; and also to answer some of the objections which have been brought against it.

Cold weather commenced on the 20th December 1840 (on which night the thermometer went down to 31°), and continued with frost every night, yet never below 26° , and with frost also through most of the day, till the 31st of the same month. By the 26th December, surface ice in considerable quantity was formed on the edges of the small river Leochal, and the temperature of the water was down to the freezing point. Down to the evening of the 28th the weather was cloudy, and there was no appearance in the river of anything resembling ground gru; but on that night the sky suddenly became clear; and before the morning of the 29th, the bottoms of all the rapids of the little river were thickly coated by the ground gru. The gru disappeared as speedily as it had formed, when, on the 29th, a close cloud, depositing slight showers of snow, again covered the whole sky, and continued till the temperature of the day and night rose above freezing.

In comparison with this, I would refer to a series of frosty days from the 1st to the 11th of February 1841, with a temperature the same as from the 22nd to 31st December, 1840, never descending below 26° . The water of the river descended to the freezing

* Part II. for 1835, p. 329.

temperature, and surface ice was formed in large quantity on the edges of both the Leochal and the Don. A dense cloud covered the sky during the eleven days and nights, and no ground gru appeared in the rivers.

A remarkable occurrence of ground gru took place in both the rivers from the evening of the 7th to the morning of the 9th January 1841, with a completely clear sky during the time. The thermometer was at 2° below zero on the night of the 7th, at 9° at mid-day on the 8th, and at 7° below zero on the night of the 8th. I examined particularly the state of the Don, during this extreme and clear frost, before it abated on the morning of the 9th. The bottom of the river was everywhere coated by an immense quantity of ground gru, excepting where it was partially shaded by bridges, or lofty banks close to the stream. In the partially shaded places the bottom was clear of gru. Thus this remarkable formation of ground gru took place under exactly such circumstances as those in which hoar-frost or dew takes place on the dry land, when the surface of the earth becomes colder than the air, (which we explain by a radiation of heat from the surface of the earth into the clear sky, or by impulses of cold from the sky to the earth,) with only this difference, that there was an additional transparent fluid over the bottom of the river, namely, the water; and thus also a shade prevented the formation of ground gru in the river, as it does that of hoar-frost or dew on the land.

In noticing the objections to the explanation I have given of the cause of ground gru, I shall confine myself to those brought forward by a writer in the Penny Cyclopædia, under the name of Ground Gru, which I have seen only very lately, although I believe they have been published for some years. He says the explanations of the formation of ground gru, given by Dr. FARQUHARSON and Mr. EISDALE, are least of all satisfactory, and adds, "The former gentleman says it is the result of radiation, and endeavours to substantiate his reasoning upon the principles of the formation of dew, seeming to forget entirely, that Dr. WELLS maintains expressly, that wind and shade are alike obstacles to radiation; and that consequently a body of moving water so deep as to be impervious to light, and particularly when covered, as in the case of the Neva, with a sheet of ice three feet thick, and as much more snow, must present an insurmountable obstacle to the radiation of heat from the bottom of the river."

Now, in the first place, with respect to shade; I was so far from forgetting that it is an obstacle to radiation, that, on the contrary, in my observations in 1835, I had shown by very many instances, that shade had prevented the formation of ground gru, just as it prevents dew. Wherever shade intervened to prevent radiation from the bottoms of the rivers Don and Leochal, there no ground ice was formed; while the unshaded parts of the bottoms were coated with it. My explanation thus mainly rested upon the fact that shade prevents radiation. In the next place, with respect to wind; the writer in the Cyclopædia himself forgets the difference of the statical conditions of air and water in connexion with temperature. Air becomes heavier by diminution of temperature. Water under 39° FAHR. becomes lighter by diminution

of temperature. During wind, on the land, the cold air at the surface of the earth is continually mixed with, or displaced by, the warmer air above; and by this process both the earth and air in contact with it are prevented from being reduced to a very low temperature by radiation. But in a body of moving water, whose temperature is under 39° , the eddies of the current throw down the coldest parts, which in still water would remain at the surface, to come into contact with the bottom. This last circumstance is the explanation of M. ARAGO; and it well accounts for the formation of ground gru taking place first in the most rapid parts of the streams; although neither by itself, nor when taken in conjunction with the other two circumstances to which he refers, namely, aptitude to formation of crystals on asperities at the bottom, and less impediment to the formation of crystals in a slower motion, will it account for the formation of ground gru, as all these circumstances are present when the water forms only surface ice. The formation of ground gru requires for its explanation an additional element, namely, the radiation, into the clear sky, of heat from the bottom of the river; and the formation never occurs but under a clear sky.

As to the ground gru, observed by Colonel JACKSON in the Neva under three feet of ice and three feet of snow, that can form no valid objection to the explanation I have given, unless it were ascertained that the gru was formed after the surface ice and the fall of the snow, and not before them. All rivers issuing from lakes, like the Neva, have very clear waters to admit of radiation through them, although as deep as it is; and all rivers are very clear during frost, owing to the freezing up of the little land rills that would convey earthy particles into them. Ground gru formed in the Neva would be much more permanent than in our rivers. The mean temperature of Alford is 45° FAHR., and that of the earth of course the same; and on the remission of its cause, the ground gru is here speedily detached from the bottom, by the transmission of heat from below. Not so in the Neva. There, according to KUPFFER, the mean temperature is only $38^{\circ}75$; and under the action of a frost so severe as to form three feet depth of ice, although the condition of the clear sky might not continue, previously formed gru would, at that mean temperature, be of great permanence. This applies also to the Siberian rivers.